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**OCEANOGRAPHIC APPLICATIONS AND LIMITATIONS OF SATELLITE REMOTE
SENSORS**

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OCEANOGRAPHIC APPLICATIONS AND LIMITATIONS OF SATELLITE REMOTE SENSORS^{1/}

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Abstract

Studies and evaluations of space oceanographic applications since 1965 have resulted in the following estimates of resolution requirements: (1) temperature to about 1° C; (2) spatial interval of 10 km.² near islands, coasts, and current boundaries, and 500 km.² in the open ocean; (3) roughness patterns outlining surface features as small as 25 km.²; (4) repetition intervals of 24 hours near coasts and 5 days over the open ocean; (5) wave heights to 5 m.; (6) wind speeds to 15 m. per sec.; (7) surface-feature resolution of 100 m.; and, (8) surface color resolution of 1,000 m. (with 100 angstrom band widths). These resolution requirements are within the apparent capabilities of earth-orbital sensor systems that will measure (a) ocean color, (b) sea-surface roughness, (c) sea-surface temperature, (d) slope of the surface ocean and (probably) of significant waves, (e) atmospheric profiles of temperature, moisture, and carbon dioxide, and (f) lunar magnitude of tide-producing forces.

Introduction

The users of ocean data acquired from space systems will be space oceanographers trained specifically to evaluate the unique features of the surface ocean. These scientists, with aid of specially designed computer programs, will reduce the data into the frame of reference suitable for the clients -- fishermen, shippers, pollution controllers, sportsmen, surfers, and the like.

The space oceanographer will need to know the wind field and wind speed; wave systems; ocean currents -- their boundaries and speeds; turbulent features, such as eddies and divergences; depth of the mixed layer (thermocline); water temperatures and their gradients; biological productivity; and fluxes of heat, moisture, and carbon dioxide.

Suitable and applicable data to satisfy these needs can apparently be acquired from

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earth-orbital sensor systems that will measure (a) ocean color, (b) sea-surface roughness, (c) sea-surface temperature, (d) slope of the surface ocean and (probably) of significant waves, (e) atmospheric profiles of temperature, moisture, and carbon dioxide, and (f) lunar magnitude of tide-producing forces. Other ocean surface features such as phosphorescence of surface oils after excitation by ultraviolet laser beams probably can be measured. The capability does not now exist, however, nor has the utility been demonstrated.

Data Resolution

The precision of measurement, and spatial and temporal repetition intervals of ocean-surface data points have yet to be established with any confidence. This shortcoming exists primarily because many of the features that we now know can be sensed, as determined from photography from manned space flights, were previously either unknown or merely suggested by data collected in the classical sea-going manner. Consequently, we have little information about the rates at which some turbulent features form -- for example, coastal eddies and convergences. Further, although we know that major ocean currents meander, with a resulting migration of the boundaries over distances of hundreds of kilometers, we have only the vaguest concept of the pulses of such perturbations, or if indeed they pulsate at all.

Nonetheless, best estimates must be made of the resolutions required for data analyses. These are, at this time: (1) temperature to about 1° C.; (2) spatial interval of 10 km.² near islands, coasts, and current boundaries, and 500 km.² in the open ocean; (3) roughness patterns outlining ocean surface features as small as 25 km.²; (4) repetition intervals of 24 hours near coasts and 5 days over the open ocean; (5) wave heights to 5 m.; (6) wind speeds to 15 m./sec.; (7) surface-feature resolution of 100 m.; and, (8) surface color resolution of 1,000 m. (with 100 angstrom band widths).

Complementary Sampling at Sea

Data derived from space systems will be reduced to a suitable form by "interpretive" computer programs. The interpretation will be based on the state-of-knowledge of the real ocean and its constituents, versus the remotely sensed data. Results, therefore, will be no better than the "ground truth" program conducted prior to the time of orbit.

Furthermore, because of the prevailing uncertainties of the rates and magnitudes of change in particular ocean waters, the experimental space program clearly requires the rational discrimination of man. The success of an operational oceanographic space system will depend entirely on well-conducted, logically designed, manned-orbiting surveys that are coupled with simultaneous oceanographic cruises, judiciously undertaken to complement the orbital paths and times of the space flights. A coordinated team effort by space oceanographers at Mission Control, at field stations, on ships at sea, in the air over the ships, and in the orbiting laboratory will be essential in the developmental program.

Personnel on the oceanographic cruises conducted simultaneously with the space flights, and during segments of the orbits of automated satellites (such as the Earth Resource Technology Satellite), will discriminatingly sample the ocean. Repeated measurements are required of water color, and the associated features; sea surface roughness, as an indicator of boundaries and wind fields; water temperature; gradients across boundaries of water masses of significant qualities such as current speed, temperature, biological constituents, and color; and surface emissions in visual, infrared, and microwave spectral bands.

Prime survey areas must be chosen where water conditions are well known from classical studies, and where the ocean contributes significantly to fisheries, oceanic productivity, or the energy budget. Ocean waters known best to the world oceanographic community should be established as "calibration sites."

From these criteria, 12 ocean areas seem suitable for prime surveys, and four as calibration sites (Table 1). Specific examples of areas considered for prime surveys and calibration tests are depicted in photographs of the Canary-Cape Verde upwelling zone, from Apollo 10, and the coast off southern California, from Apollo 11.

Such a space oceanography program requires international cooperation, coordination, and integration. This step is logical in the development of any earth-resource satellite system because orbits are necessarily "international." Beyond that, however, the ocean features that must be defined, the repetition intervals that must be ascertained, and the relationships that must be established between remotely sensed data and the beneficial "product," require oceanographic efforts greater than the existing capabilities of any single nation. With these thoughts in mind and considering the growing number of experimental orbiting systems planned for the 1970's, it seems clear that the space oceanography program fits well with the concept of an International Decade of Ocean Exploration.

Major Ocean Areas and Specific Sites	Type of Study
<u>Atlantic Ocean</u>	
Caribbean-Gulf of Mexico-Gulf Stream System; Barents, North, Norwegian, Baltic, and Icelandic seas; Gibraltar-Canary Islands-Cape Verde upwelling zone; Benguela Current off southwest Africa.	Prime Survey
North and Norwegian seas.	Calibration Test
<u>Indian Ocean</u>	
Somali upwelling zone-western equatorial divergence-Agulhas Current; monsoon drift in the Bay of Bengal; upwelling zone northwest of Australia and the West Australian Current.	Prime Survey
<u>Mediterranean Sea</u>	
Western basin.	Prime Survey
<u>Pacific Ocean</u>	
Kuroshio Current system-Gulf of Alaska; equatorial system in southern Micronesian and Melanesian waters; sea off southern California; Humboldt Current.	Prime Survey
Sea off southern California; waters southeast of Australia-Tasman Sea; Sea of Japan.	Calibration Test

TABLE 1 MAJOR OCEAN AREAS WITH SITES FOR PRIME SURVEYS AND CALIBRATION TESTS

The Goal

Through the years of experiments that will culminate in an operational application satellite information system, the goal of the space oceanographer is to develop a model of the ocean so precise that daily predictions are made of any ocean condition significant to the interests of the clients. The role of the space system is to sense the real-time deviations from the predicted ocean. Wherever and whenever the deviations become great enough, a new base will be established for the predicted model on which the succeeding data will impact. In this way, the ocean will be viewed during each repetition interval, but computer analyses will function only from significant deviations.

Remarks

I have purposely avoided discussing the "frame-of-reference" information desired by the clients; that is, the practical applications and associated techniques of a space oceanographic satellite system. I feel no hesitation, however, in stating that it will lead to that age-old dream of man -- manipulation and control of ocean environments, and the indigenous biological constituents. The magic potion that changes the dream to reality is, of course, the capability to measure continuously the ecology of the world ocean.

Technology exists now for the development and implementation of earth-resource satellite systems. No breakthroughs are necessary, only the will and the effort. Apollo 12 is the best example of the perfection that can be achieved when there is the will to do it. The will and the effort must prevail for an earth-resource system, for when a fully operational application satellite information system is orbiting the earth, it is imperative for the United States flag to be on the spacecraft.

Suggested Readings

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